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TIME DEPENDENCE OF HEAVY ION CONCENTRATION IN THE RING CURRENT

Mary K. Hudson

Dartmouth College
Hanover, NH 03755

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AIR FORCE SYSTEMS COMMAND
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

"This technical report has been reviewed and is approved for publication"

Kevin J. Kerns

KEVIN J. KERNS, LT, USAF
Contract Manager

E. G. Mullen

E. G. MULLEN
Branch Chief

William Swider

WILLIAM SWIDER
Deputy Director

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13. ABSTRACT (Maximum 200 words)

The focus of this project has been a comprehensive study of processes responsible for the decay of the storm time ring current. We have examined the importance to ring current ion loss of interaction with waves in the Pc 1 (Hz) and Pc 5 (mHz) frequency ranges, since such waves are a common feature of the ring current region during recovery from magnetic storms. Pc 1 waves, identified as electromagnetic ion cyclotron (EMIC) waves, are generated by the loss cone distribution of ring current ions. We have performed both linear dispersion analysis and particle simulations which show the importance of the loss cone vs. bi-Maxwellian nature of ring current ion distributions in determining the growth rate, angle of propagation and polarization of EMIC waves. Pitch angle diffusion is found to be an important loss process for ring current H^+. Compressional Pc 5s are found to contribute to ring current O^+ loss. Their frequency (2-5 mHz) is comparable to the bounce frequency of ring current O^+. We have performed ring current test particle simulations in prescribed wave and background fields, including a dipole magnetic, convection and corotation electric field. We find that a drift-bounce resonant interaction causes ring current O^+ loss to the magnetopause in the energy range of a few tens of keV for moderate Kp (1.5 - 2).

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Figure Captions

Fig. 1. Plot of energy versus azmuthal angle (positive westward) or local time for an ion injected at 1800 LT. The solid line represents the minimum energy required for the ion to drift westward without Pc 5 waves. The dashed line represents the energy variation under the effect of the convection and corotation electric fields, without Pc 5 waves, for a 28 keV ion injected at 1800LT; the dotted line is for the same case with Pc 5 waves included.

Fig. 2a. The equatorial trajectories of 132 0^+ ions with different initial energies: 26.00 keV to 31.00 keV, in steps of 0.50 keV; equatorial pitch angles: 15° to 75°, in steps of 20°; and L shells: L = 6.0 to L = 7.0, in steps of 0.5; the same initial gyrophase (= arctan (v_y/v_x)), $v_x = v$, $v_y = v_z = 0$. Here the Pc 5 wave has ten different azimuthal wave numbers, ranging from m = 95 to m = 105, each with a random initial azimuthal phase and the same amplitude, which now is reduced by $1/\sqrt{10}$. The azimuthal wave number determines the perpendicular wavelength $\lambda_\perp = 2\pi\ LR_E/m$.

Fig. 2b. Numbers of ions in 2 keV bins, integrated over L, for parameters of (a).

TIME DEPENDENCE OF HEAVY ION CONCENTRATION IN THE RING CURRENT

The focus of this project has been a comprehensive study of processes responsible for the decay of the storm time ring current. We have examined the importance to ring current ion loss of interaction with waves in the Pc 1 (Hz) and Pc 5 (mHz) frequency ranges, since such waves are a common feature of the ring current region during recovery from magnetic storms.

Pc 1 waves, identified as electromagnetic ion cyclotron (EMIC) waves, are generated by the loss cone distribution of ring current ions, analogous to their generation by radiation belt ions, which has been shown to determine the limit on stably trapped radiation belt ion fluxes (Kennel and Petchek, 1966). We have performed both linear dispersion analysis and particle simulations which show the importance of the loss cone vs. bi-Maxwellian nature of ring current ion distributions in determining the growth rate, angle of propagation and polarization of EMIC waves. In contrast to the conventional picture that EMIC waves are predominantly parallel propagating relative to $\mathbf{B}_o$, left hand polarized transverse ($\delta E \perp \mathbf{k}$) modes, recent observations have

found that EMIC waves are commonly linearly polarized (Anderson et al., 1990). We have obtained a simple explanation for these observations, showing that a loss cone distribution generates obliquely propagating EMIC waves which are quasi-electrostatic, linearly polarized and analogous for ions to whistler modes on the electrostatic resonance cone (Denton et al., 1991).

We have shown that EMIC waves are effective at causing pitch angle diffusion of ring current H^+ into the loss cone, thereby providing a loss mechanism for enhanced storm time fluxes (Qian et al., 1990). EMIC waves are less effective at causing pitch angle diffusion of ring current O^+, since O^+ is a minor constituent of the cold background plasma, and the O^+ cyclotron mode is not easily excited. This finding led us to the investigation of lower frequency modes in the Pc 5 range.

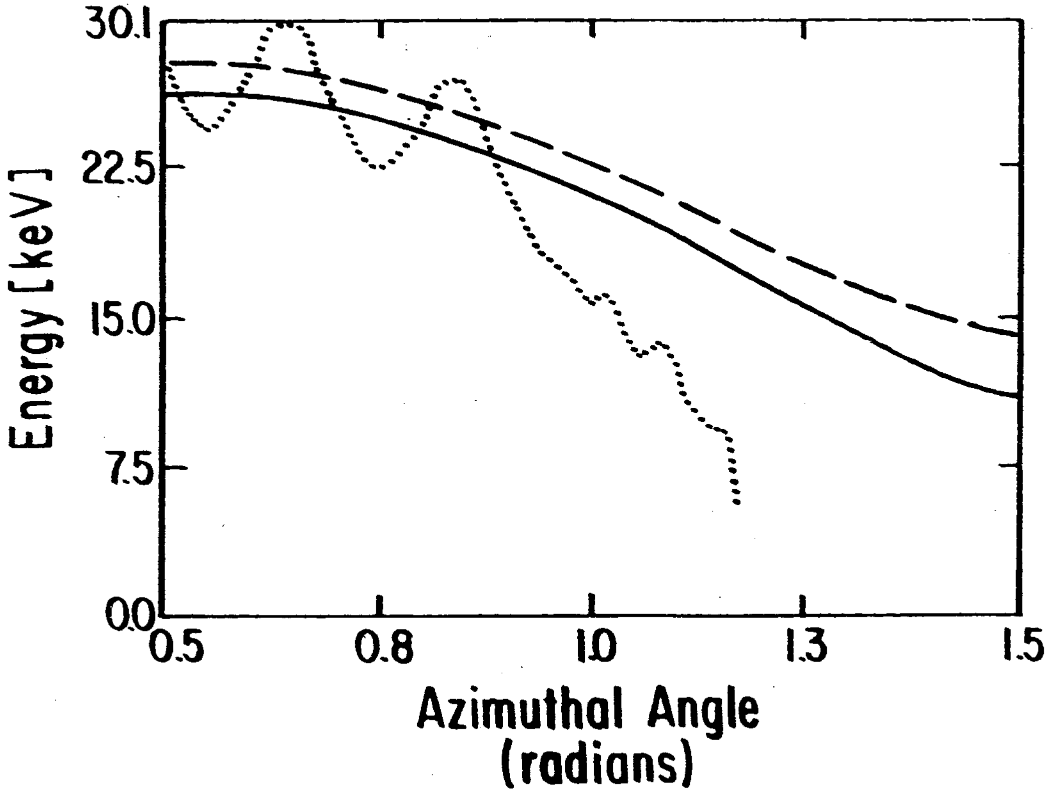
Pc 5 micropulsations are a completely different class of modes from EMIC waves. The latter are generated locally by the ring current ion loss cone, which is enhanced by global effects like drift shell splitting. The former is a global oscillation of the earth's magnetic field which may be driven internally by pressure gradients and particle resonances, or externally by changes in solar wind pressure at the magnetopause. We have concentrated on a class of internally driven, so called compressional Pc 5s which are commonly observed during the recovery phase of magnetic storms. Their frequency (2-5 mHz) is comparable to the bounce frequency of ring current O^+ and it has

been suggested that they may contribute to O^+ loss via a bounce resonance (Cladis and Lennartsson, 1986).

We have performed ring current test particle simulations in prescribed wave and background fields, including a dipole magnetic, convection and corotation electric field. We find that a drift-bounce resonant interaction causes ring current O^+ loss to the magnetopause in the energy range of a few tens of keV for moderate Kp (1.5 - 2). The compressional Pc 5s are standing waves along $\mathbf{B}_o$ which propagate azimuthally in the direction of ring current ion drift. Thus it is possible for ring current ions in the right energy range to remain in phase with a single mode Pc 5 wave and either gain or lose energy from the wave fields. An ion which loses energy may not be able to overcome the convection potential across the dayside, as Figure 1 indicates. It will then $\mathbf{E} \times \mathbf{B}$ drift to the magnetopause.

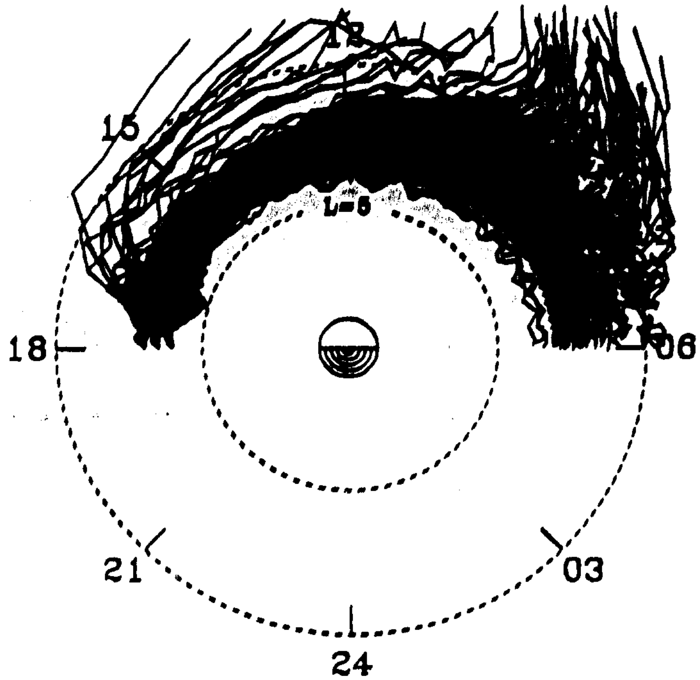
While Pc 5s are often highly monochromatic, appearing almost sinusoidal in satellite magnetometer data, some spread in azimuthal mode number (perpendicular wavelength) is expected. If we assume a 10% spread in perpendicular wavelength, but the same total power in $\delta B/B_o$, the ion motion becomes diffuse in energy and L. The type of diffusion seen as a function of local time is apparent in the plots of ion number vs. energy in 2 keV bins shown in Fig. 2. One sees a bulk shift to lower energy due to the convection electric field as ions drift across the dayside, along with a spread to higher and lower energies associated with radial

diffusion. We have integrated the radial diffusion equation using a coefficient appropriate for the Pc 5 wave interaction described in Quarterly Report Number 9, and find good agreement with the numerical results (Li et al., 1991). Papers by Denton et al. and Li et al. are available upon request, and will be appended to Quarterly Report Number 17.



30.1
22.5
15.0
7.5
0.0
Energy [keV]
0.5
0.8
1.0
1.3
1.5
Azimuthal Angle
(radians)

Figure 1



NPART=132 NOUT= 68 NPASS= 64

phim=95 f=0.002 bd=0.04 rkz=2.7 n=0 wphi0=0. rl0=7. a0=2 modl=10
econ=1 ecor=1 rkp=1.5 phi0=90 gphase0=0 gphased=0 am=16
ekt0=26. ektd=0.5 npe=11 pitch0=15 pitchd=20 nppitch=4
rlp=6.0 rld=0.5 npl=3 ntmax=400000 err=1.e-05

Figure 2a

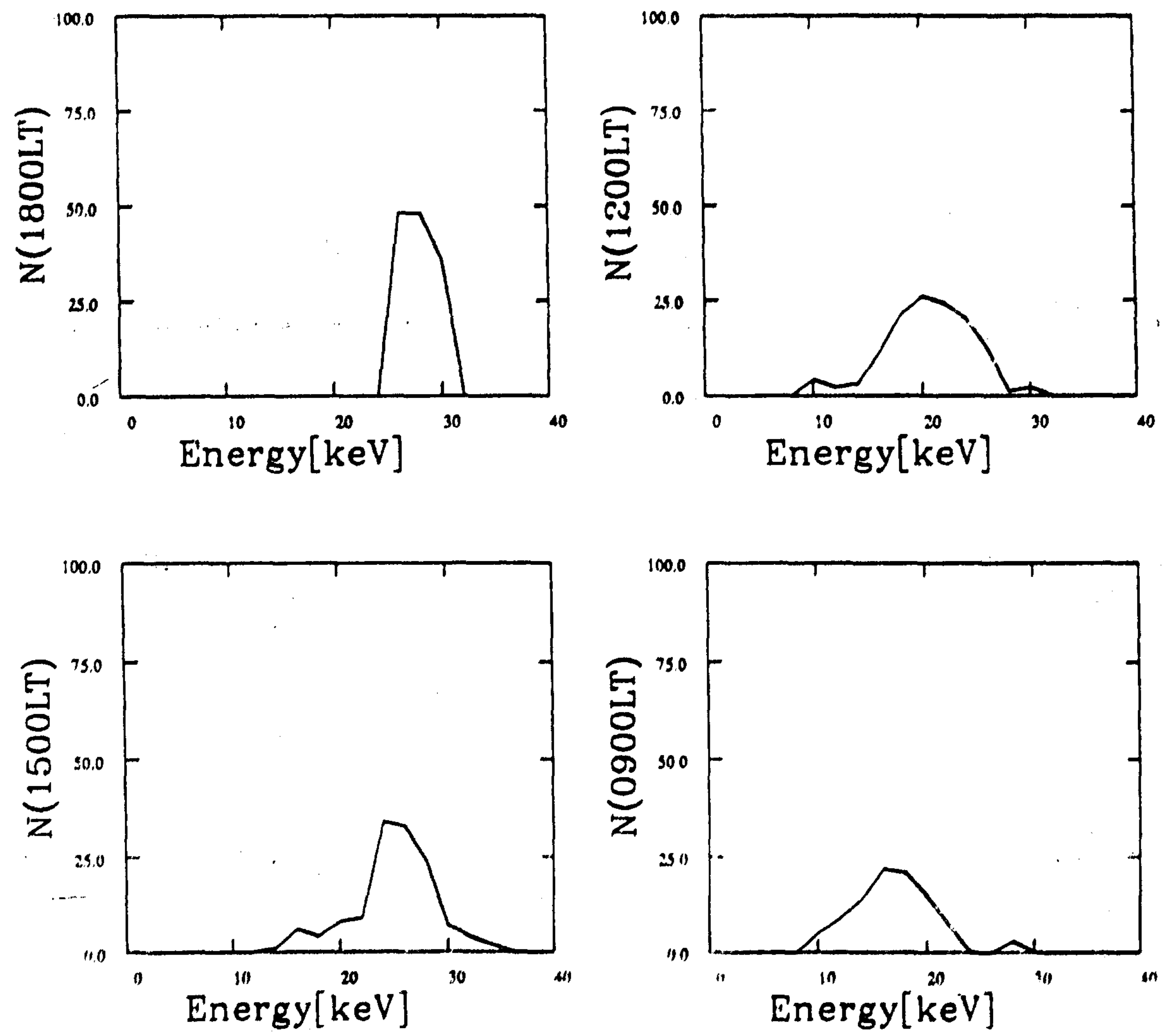

100.0
75.0
50.0
25.0
0.0
N(1800LT)
0
10
20
30
40
Energy[keV]
100.0
75.0
50.0
25.0
0.0
N(1200LT)
0
10
20
30
40
Energy[keV]
100.0
75.0
50.0
25.0
0.0
N(1500LT)
0
10
20
30
40
Energy[keV]
100.0
75.0
50.0
25.0
0.0
N(0900LT)
10
20
40
Energy[keV]

Figure 2b

References

Anderson, B.J., K. Takahashi, R.E. Erlandson and L.J. Zanetti, Pc 1 pulsations observed by AMPTE/CCE in the earth's outer magnetosphere, Geophys. Res. Lett., 17, 1853, 1990.

Cladis, J.B. and O.W. Lannartsson, On the loss of O^+ ions (< 17keV/e) in the ring current during the recovery phase of a storm, in Ion Acceleration in the Magnetosphere and Ionosphere, Tom Chang, ed. AGU, Washington, D.C., pp. 153-157, 1986.

Denton, R.C., M.K. Hudson and I. Roth, Magnetospheric ion cyclotron waves with oblique propagation, submitted to J. Geophys. Res., 1991.

Kennel, C.F. and H.E. Petchek, Limit on stably trapped particle fluxes, J. Geophys. Res., 71, 1, 1966.

Li, X., A. Chan, M.K. Hudson and I. Roth, Loss of O^+ ions in the ring current due to interaction with Pc 5 waves, submitted to J. Geophys. Res., 1991.

Qian, S., M.K. Hudson and I. Roth, Particle simulation of ion heating in the ring current, J. Geophys. Res., 95, 1001, 1990.